Journal of the Institute for Educational Research
Volume 55 • Number 2 • December 2023 • 275–299
UDC 159.947.5-057.875(497.113)
159.953.5-057.875(497.113)
378.147::53

ISSN 0579-6431
ISSN 1820-9270 (Online)
https://doi.org/10.2298/ZIPI2302275C
Original research paper

THE IMPACT OF PROJECT-BASED LEARNING IN PHYSICS EDUCATION ON UNIVERSITY STUDENTS' MOTIVATION TO LEARN AND METACOGNITION*

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ABSTRACT

Project-based learning, involving an interdisciplinary approach, can be applied in the treatment of the content of various teaching subjects. It is also applicable at the university level. The aim of this research was to examine whether project-based learning could enhance students' motivation to learn physics and their metacognitive awareness. Therefore, a pedagogical experiment with one group was applied. The sample consisted of 94 first-year students from the Faculty of Sciences and the Faculty of Technology at the University of Novi Sad. A pedagogical experiment was applied, and statistical analysis of the collected data was conducted. Project-

* *Note*. This research paper originated from the results of a study conducted within the framework of a doctoral dissertation at the Faculty of Sciences, University of Novi Sad.

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based learning was implemented in addressing the topic of Diffusion and Osmosis, which involves the integration of content from biology, physics, and chemistry. Students created eighteen projects, and their products were video materials. The data collection technique was the use of a questionnaire. The research results showed that there was no significant difference in students' motivation before and after the implementation of project-based learning. However, a statistically significant difference was found in students' metacognition before and after the application of project-based learning. The results of this research suggest the need to encourage the implementation of project-based learning in university education with the aim of increasing students' metacognitive awareness and further enhancing the implementation of project-based learning to positively impact students' motivation for learning.

Key words:
metacognition, motivation to learn, project-based learning, university education.

INTRODUCTION

In order to successfully master university physics curricula, students need to possess appropriate knowledge from other natural sciences, mathematics, and language, as well as the skills required for problem-solving and conducting experiments. Due to the complexity and abstract nature of physics, student-oriented teaching approaches need to be applied in physics teaching to encourage motivation for learning and metacognition. These approaches often involve conceptual learning, inquiry-based learning, and problem-solving (Orlich et., 2007). Project-based learning can also be applied in physics teaching. When teaching is focused on the student as the subject, rather than the object of instruction, positive student attitudes toward the studied content are formed, i.e., the acquisition of knowledge is facilitated and the development of metacognition is encouraged (Das, 2021).

However, a general trend of declining interest in natural sciences among students has been observed. Numerous reasons contribute to this, particularly in Western European countries. According to Schreiner & Sjøberg (2010), these reasons primarily include outdated curricula, a lack of sufficiently qualified teachers, stereotypically negative perceptions of scientists, a lack of role models in science, alternative religious explanations for scientific phenomena, postmodern attacks on science, and skepticism towards modern ambitious and complex scientific research. It has also been observed that knowledge in the field of natural sciences is inversely correlated with interest in the natural sciences. Accordingly, students from less developed countries, with less knowledge in the natural sciences, tend to express greater interest in the natural sciences compared to students from developed countries who have more extensive knowledge in the natural sciences (Schreiner & Sjøberg, 2010).

Additionally, it has been shown that by the age of fourteen, students mostly have formed opinions about the natural sciences. Besides age, gender can also be a determining factor in interest in the natural sciences. It has been found that male students express greater interest in engaging with the natural sciences (Chow & Young, 2013; Griethuijsen et al., 2015). There is an observed decline in the use of practical and laboratory work methods in natural science education (Ma et al., 2017). Hence, it is particularly important to enrich natural science teaching content with information about the historical development of science, research anecdotes, replicas of old experiments, and laboratory procedures. This approach aims to help students better understand scientific content and increase their interest in the natural sciences (Heering & Höttecke, 2014), while engaging students in laboratory and practical activities.

When a person is motivated, they will strive to direct their activity towards a specific goal, be willing to invest effort, and persevere in achieving that goal (despite any eventual obstacles and challenges encountered) (Lalić-Vučetić, 2015). Motivation in education enables the direction of the teaching process towards the free and spontaneous activation of students' internal forces (Lalić-Vučetić, 2015). Motivation to learn can be distinguished as one type of motivation (Brophy, 2010). It involves students' tendency to recognize the meaning, significance, and value of academic activities or to achieve academic success (for example, obtaining a high grade) (Trebješanin, 2009). Gaining new insights into motivation to learn and its enhancement is important, not only from a scientific standpoint but also for the teaching process.

It has been shown that the motivation of students in natural sciences is positively correlated with their academic achievements (Llbao et al., 2016). Additionally, a significant factor is the quality of educational experiences provided by natural science teachers, with the quality of teachers' work being a crucial factor for student motivation (Osborne & Collins, 2001; Schreiner & Sjøberg, 2004).

Project-based learning has a proven positive effect on the motivation of students in natural and technical sciences (Ocak & Çelebi, 2010; Terrón-López et al., 2017). It has been found that the level of control possessed by the teacher in project-based learning, as well as the quality of students' teamwork, particularly impact student motivation (Hilvonen & Ovaska, 2010).

Like motivation, metacognition is a complex concept, and there is no single definition of metacognition. Metacognition refers to awareness and knowledge of one's own cognitive processes, monitoring, and managing one's own cognition and behavior (Mirkov, 2006). Simply put, metacognition is "knowledge about knowledge," "thinking about thinking," or "cognition about cognition." Different authors have identified various components within metacognition. For example, awareness of metacognitive knowledge, metacognitive regulation, and metacognitive experiences (metacognitive events) can be distinguished. Metacognitive knowledge relates to declarative, procedural, and conditional knowledge (Schraw & Moshman, 1995), while metacognitive regulation involves processes for regulating cognitive processes, such as planning, information management, monitoring, debugging, and evaluation in the process of thinking and learning (Schraw & Dennison, 1994). Metacognitive experiences include an individual's sense of knowing something, «the tip of the tongue» feeling when trying to recall information, and other experiences before, during, and after cognitive processes (Hacker, 1998). The significance of metacognition for successful learning is substantial, especially in the learning of complex content, such as physics. Metacognition involves awareness of one's own efficiency and self-regulation (Cera et al., 2013). Individuals with highly developed metacognition are successful in learning, aware of their strengths and weaknesses, and choose a method that suits them best. They have various learning and problem-solving strategies at their disposal and know how to recognize the appropriate learning strategy in a particular situation.

Teaching and learning natural sciences are complex processes, both due to the content and the thinking skills required to understand science at a sufficiently deep level to be meaningful and useful. Metacognition assists natural science teachers in reflecting on how they manage the curriculum, teaching, and assessment. It also aids them in systematically contemplating what they present to students, why, and how. Metacognition benefits students learning natural sciences by enabling them to apply and develop effective strategies for acquiring, understanding, applying, and retaining comprehensive and challenging concepts and skills (Hartman, 2001).

Efficient natural science teaching requires the application of metacognitive abilities by teachers and the development of these abilities in students. It has been proven that active and meaningful learning with the involvement of metacognitive processes of both students and teachers positively influences the quality of natural science education, learning outcomes, and student achievements in these areas (Avargil et al., 2018). Therefore, it is crucial to implement problem-solving learning, collaborative learning, discovery-based learning, and the use of various structured visual technologies such as concept maps and diagrams in natural science education (Sanium & Buaraphan, 2019; Veenman, 2012).

Project-Based Learning

In project-based learning, the student is at the center of the educational activity, actively engaging in the learning process (Quint & Condliffe, 2018), aligning this didactic model with the constructivist paradigm of learning. Project-based learning involves learning through work, with a focus on real-life problems that capture the individual's attention (Bell, 2010). These problems are often complex and open-ended, requiring research for their resolution. One of the fundamental characteristics of project-based learning is that students work on creating certain products, that is, implementing projects (Ravitch, 2000; Savery, 2006). Moreover, four basic principles underlie project-based learning. These include active knowledge construction, learning situated in a specific context, social interaction, and the use of cognitive tools or educational technologies that support students in acquiring knowledge (Miller & Krajcik, 2019).

Project-based learning, in the initial phase of its implementation, involves planning project activities, i.e., defining expected knowledge and skills through learning outcomes by the teacher (Larmer & Mergendoller, 2010). Subsequently, in the next phase, the formulation of driving questions takes place to motivate students for their work. In this phase, students become active participants. The motivation for learning stems from questions that students identify, defined in the process of developing their scientific ideas supported by teachers (Guy-Gaytán et al., 2019). These driving questions are characteristic elements of project-based learning, helping students find meaning and relevance in a phenomenon, fostering their curiosity, and cultivating interest in science. This creates an environment where students can pose questions, seek answers, express their observations, and formulate claims about scientific phenomena independently (Miller & Krajcik, 2019).

To implement project-based learning, teachers take on the role of coordinators (Stojanović, 2017). They should model the stages of project work but refrain from taking control over project development (Lakkala et al., 2005). Teachers facilitate project-based learning by encouraging students to be active, assisting them in selecting methods and tools, and promoting collaboration during the project development and knowledge acquisition process (Grant, 2002). The next step involves the design of the project by students, a complex task that requires a significant amount of time. Subsequently, students or groups of students present their projects publicly. In the final phase, during the project evaluation process, the assessment considers whether the project addressed the driving questions. After analyzing the presented projects and engaging in discussions among teachers and students, revisions and improvements of these projects take place. This is crucial to enable student reflection, provide teacher feedback, and publicly present all the projects students have undertaken (Krajcik & Shin, 2014). The final products of project-based learning can vary, including academic dissertations, presentations, reports, exhibitions, video materials, social games, and more (Botha, 2010; Nation, 2008).

Since projects can simultaneously encompass various disciplines in the natural and social sciences and involve diverse activities, project-based learning easily achieves an interdisciplinary approach, which is its important characteristic. Through interdisciplinary approaches, students are encouraged to take a holistic approach to problem-solving and adapt to different curriculum contents, regardless of the differences that exist between various subjects and disciplines (Harmer & Stokes, 2014).

Project-based learning is a didactic model that can be applied in physics education and other natural science education settings (Colley, 2008; Holubova, 2008; Kubiatko & Vaculova, 2012). Interdisciplinarity within project-based learning can stimulate the development of metacognition (Malinić et al., 2021) and motivate students to learn (Chiang & Lee, 2016). It has also been confirmed to have a positive impact on the academic achievements of students (Chen & Yang, 2019; Stojadinović et al., 2021), as well as on building positive attitudes of students toward the content and the implementation of that content (Çelik et al., 2018; Čavić et al., 2022). Therefore, it is essential to examine the impact of project-based learning on the motivation and metacognition of students.

Research Aim and Tasks

Based on the outlined characteristics of project-based learning, this research applied this didactic approach in presenting interdisciplinary concepts of *Diffusion and Osmosis* in university-level physics education. In one part of this study, it was determined that students had positive attitudes toward project-based learning (Čavić et., 2022), while the aim of the second part was to examine the impact of implementing project-based learning in addressing the mentioned concepts on the metacognition and motivation of first-year students at the Faculty of Sciences and the Faculty of Technology at the University of Novi Sad (hereinafter referred to as "students").

In accordance with the set aim, the following tasks were defined:

1. Examine the impact of project-based learning in physics on the motivation of the surveyed students.
2. Determine whether there are differences in the motivation to learn physics among the surveyed students based on gender, study program, and academic achievements.
3. Examine the impact of project-based learning in physics on the metacognition of the surveyed students.
4. Determine whether there are differences in the metacognition of the surveyed students based on gender, study program, and academic achievements.

METHOD

Research Sample

The initial sample in the research consisted of 94 students who enrolled in the first year of studies at the Faculty of Technology and the Faculty of Sciences (Department of Physics) at the University of Novi Sad during the 2018/19 academic year. Technology students were enrolled in one of the following study programs: Food Engineering, Pharmaceutical Engineering, Materials Engineering, and Biotechnology. Physics students were enrolled in the Physics and Physics Teacher programs. A convenience sample was used. All students who were attending some type of classes held by the researcher at the time when the research was carried out participated in the research. With these students, the implementation of project-based learning was possible in the integration of selected curriculum content. The students voluntarily participated in the research, providing formal consent individually. Privacy was respected throughout the research, ensuring no influence on the participants. Students were free to express their opinions anonymously. As not all students participated continuously, and some lacked complete data, the analysis was conducted based on information from 62 students from the initial sample.

The topic of Diffusion and Osmosis was addressed with the students because within its scope there are important interdisciplinary correlations between physics, chemistry, and biology. Project-based learning can assist in mastering integrated content, as well as in further expanding the physics curriculum and highlighting existing correlations.

Research Methods, Organization, and Procedure

A pedagogical experiment was conducted with one group, where the research was carried out outside the regular classes attended by the students. Students were rewarded with an additional maximum of five exam points for the course they attended, in whose implementation the researcher participated. These courses were Thermodynamics for physics students and (General) Physics for technology students. Over six weeks (during May and June), the researcher met with the students once a week for two hours. During the first session, the researcher explained the basic principles of project-based learning to the students. In the next session, the driving questions and study objectives for the topic of Diffusion and Osmosis were defined. This topic was assigned to the students due to its relevance to the mentioned study programs and because it was part of the material they had studied (though not in great detail) within the mentioned courses. Based on the assigned topic, students created projects according to their interests and experiences. The driving questions were defined collaboratively by the students and the researcher. The researcher played the role of coordinator, while students had the freedom to ask questions or modify their colleagues' suggestions. Questions varied for different groups of students. For example, for the group of students in the Physics Teacher program at the Department of Physics, the driving question was: *How could the topic of Diffusion and Osmosis be utilized to connect content from different subjects and create an understanding of the integrality of knowledge learned in various classes?* For the research-oriented students: *How do various factors, such as temperature and solution concentration, affect the speed of diffusion and osmosis?* For the group of technology students: *How are diffusion and osmosis used in the food industry?* Students were organized into groups of three or four members based on common interests. Introducing group work was not a problem, as students were accustomed to this form of work in mandatory laboratory exercises. The project aimed to create video material containing an explanation of the processes of diffusion and osmosis, as well as its demonstration through an experiment and analysis of the relationship between physical, chemical, and biological concepts and laws related to these processes. The project consisted of students studying video recordings on the selected topic that they independently searched, mainly through the internet, primarily via YouTube, and creating their own video recordings and experiments. Additionally, students studied literature, mainly provided by the researcher, often related to scientific disciplines that were not their specific field of study, to enhance the project's interdisciplinary aspect.

In addition to the above, students sought assistance from the researcher in the form of recommendations for using computer programs for editing videos and other multimedia content (for example, software applications for video editing like *Legacy Video Editor* and *YouTube Video Editor*). They also had the opportunity to discuss and verify their understanding and ideas. To receive feedback from the researcher during the project implementation, students discussed their ideas, plans, materials used, and their understanding of the content. This way, they gained confirmation that they were doing well, or they obtained suggestions to make changes.

When the projects were finalized, each group prepared a project report explaining its purpose and providing basic information about its goals and scope. The report also included a self-evaluation of the project's success (e.g., whether the intended content was learned, whether teamwork was achieved). Subsequently, they presented their projects to other students and the researcher. Each group implemented one project, resulting in a total of 18 different projects with video material created during the research. Some video recordings resembled episodes of a documentary show, some showed the performance of the experiments, and some project presentations resembled lectures with video material complementing the lesson. After each presentation, a discussion followed, and each project was considered and descriptively evaluated, both by the researcher and by colleagues who were allowed to comment on the project. The evaluation included determining what new content students learned through project execution, whether they developed skills necessary for collaborative and teamwork, whether all individuals were engaged so that everyone could succeed as a team, and whether they encountered difficulties in collaboration. Additionally, the evaluation assessed whether they mastered the application of new technology, improved communication skills, and presentation skills. Students were free to highlight ideas they liked and compare similar projects. When all project presentations were completed, students were given a questionnaire. The questionnaire was anonymous, and the allotted time for completing the questionnaire was 35 minutes.

Data Collection Techniques and Instruments

For data collection, a questionnaire was used. As suggested for similar research (Segedinac et., 2011), an expert team was formed to assess the questionnaire's validity. This team, consisting of three university professors, assessed that the questionnaire items were suitable for students as all formulations were precise and understandable. The initial section of the questionnaire gathered data on students' gender, study program, and academic success (average grade in studies). Subsequently, using appropriate scales (each described separately as adapted versions of suitable instruments), the motivation to learn physics (items related to subject learning were focused solely on physics) and students' metacognitive awareness were assessed.

An adapted Serbian version of the questionnaire on students' motivation to learn chemistry (Olić et al., 2016), prepared based on the motivation questionnaire for learning natural sciences (Student's motivation toward science learning, Tuan, Chin, & Shyang, 2005), was applied to examine students' motivation to learn physics. The adapted questionnaire consisted of 29 items with responses on a 5-point Likert scale. These items covered five aspects of motivation: self-efficacy, active learning strategies, understanding the importance of physics as a science, performance goal and achievement goal (more details about the questionnaire can be found in the dissertation, Olić, 2016). In this research, the questionnaire assessed only the students' motivation to learn physics, while students' attitudes toward implementation of projects were examined using another scale (in which some items could be related to motivation to work on projects) and analyzed in another publication (Čavić et al., 2022). The initial test's Cronbach's alpha coefficient for this part of the instrument was 0.85, and for the final test, it was 0.89. Therefore, these scales can be considered reliable for use in the research sample.

Students' metacognitive awareness was assessed with the Serbian version of the Metacognitive Awareness Inventory (Bogdanović et al., 2015), translated and adapted from an inventory created to assess metacognitive abilities in adolescents and adults (Metacognitive Awareness Inventory, Shraw & Dennison, 1994). The applied questionnaire was in the form of a 5-point Likert scale and contained 32 items out of the original 52. The questionnaire covered the following metacognitive components: declarative knowledge, procedural knowledge, conditional knowledge, planning, information management, monitoring, debugging, and evaluation. The adapted questionnaire proved applicable for participants in this research. The Cronbach's alpha coefficient for this part of the instrument was 0.76 and 0.86 on the initial and final tests, respectively, indicating satisfactory reliability of the applied scale.

Data Processing Methods

For both, students' motivation and metacognition, the differences between the scores on the initial and final tests were examined using a paired-sample t-test (since results of Shapiro-Wilk test confirmed that the data satisfy the criteria of normal distribution). Motivation and metacognition concerning the participants' gender, study program, and achievements (categories will be formed based on the number of passed exams and the average grade) were examined using an independent-sample t-test. The results of Shapiro-Wilk test are presented in the table, in Appendix.

RESEARCH RESULTS

The Analysis of Students' Projects and Prepared Video Materials

The analysis of students' projects showed that the students achieved the set goals: they mastered basic knowledge of diffusion and osmosis (to a greater or lesser extent), expanded their understanding of these phenomena from the perspectives of other disciplines, and some individuals acquired new skills, such as working with software they had not used before. The projects varied in terms of the quality of execution and product. Although it was not specifically investigated, the researcher observed during the implementation of project-based learning that the quality of student work was higher when students consulted with the professor more frequently. However, without additional research, no conclusion can be drawn about this. It is possible that students who invested more effort in project development consulted with the professor more often, or that students needed help from the professor for success. The quality of ideas differed, and the quality of project execution and presentation did not necessarily correspond to the quality of the idea. The engagement of individual students within the group during project work varied. Each student had a specific responsibility within each group, but it was evident that in some groups not all group members were equally informed about segments of project work. It was shown that students developed a positive attitude towards project-based learning (Čavić et al., 2022).

Some projects had only video material as the final product, resembling a short documentary film presented in the form of a science lecture. Some projects created by students in the Physics Teacher program were designed as a classroom lesson where the video material they produced was an integral part of the lecture. One group of students made several short video clips presenting simple home experiments, and these clips were intended for promoting science through platforms like YouTube, TikTok, and similar internet applications.

The Impact of Project-Based Learning on Students' Motivation to Learn Physics

To examine whether project-based learning influenced students' motivation to learn physics, a paired samples t-test was performed (Table 1). In order to investigate the impact of project-based learning on students' motivation to learn physics, the summative score on the corresponding scale was analyzed. Higher summative scores indicate greater students' motivation to learn (the highest possible value was 145, and the lowest was 29).

Table 1. Results of paired samples t-test: exploring the difference in motivation before and after the introduction of project-based learning for different groups of students

Student Group	Test	N	M	SD	t	df	p
Whole sample	Initial	62	125.81	10.49	-0.08	61.00	0.94
	Final		129.47	12.64			
Male students	Initial	16	100.62	13.33	-0.89	15	0.38
	Final		129.19	13.79			
Female students	Initial	46	101.67	10.56	0.52	45.00	0.60
	Final		129.57	12.37			
Physics students	Initial	20	105.40	12.84	-1.77	19.00	0.09
	Final		109.20	8.36			
Technology students	Initial	42	99.50	9.99	1.20	41.00	0.24
	Final		97.83	11.73			
Low performance students	Initial	21	101.81	10.62	0.53	20.00	0.60
	Final		100.95	10.31			
Average performance	Initial	26	104.92	9.74	0.16	25.00	0.88
	Final		104.73	11.03			
High performance	Initial	15	94.73	12.16	-0.49	14.00	0.63
	Final		96.67	14.46			

According to the results presented in Table 1, there is no statistically significant difference in motivation to learn physics before and after the introduction of project-based learning for different groups of students (for all analyzed groups, $p>0.05$).

The Impact of Project-Based Learning on Students' Metacognition

To examine whether project-based learning influenced students' metacognition, a paired samples t-test was performed (Table 2). A higher summative score on the corresponding scale indicated greater metacognitive awareness of students, with values ranging from 32 to 160.

Table 2. Results of paired samples t-test: exploring the difference in metacognition before and after the introduction of project-based learning for different groups of students

Student Group	Test	N	M	SD	t	df	p
Whole sample	Initial	62	125.81	10.49	-2.98	61.00	0.004
	Final		129.47	12.64			
Male students	Initial	16	124.19	10.72	-2.44	15.00	0.03
	Final		129.19	13.79			
Female students	Initial	46	126.37	10.47	-2.13	45.00	0.04
	Final		129.57	12.37			
Physics students	Initial	20	123.90	9.78	-3.56	19.00	0.002
	Final		130.20	14.70			
Technology students	Initial	42	126.71	10.80	-1.52	41.00	0.14
	Final		129.12	11.71			
Low performance students	Initial	21	125.76	8.80	-1.53	20.00	0.14
	Final		129.43	12.71			
Average performance	Initial	26	125.92	11.34	-1.79	25.00	0.09
	Final		128.58	13.28			
High performance	Initial	15	125.67	11.78	-1.85	14.00	0.09
	Final		131.07	12.10			

Results presented in Table 2 indicate that there is a statistically significant difference in students' metacognition between the initial and final tests, observed for the entire sample, as well as separately for male and female students, and physics students. However, for other groups of students, it has been shown that there is no statistically significant difference in metacognition before and after the introduction of project-based learning.

DISCUSSION

In this research, students' motivation and metacognition were measured before and after the introduction of project-based learning, using self-assessment scales. While certain groups of students demonstrated an increase in metacognitive awareness, no change in motivation to learn was observed in any group of students.

In this research, it was not demonstrated that the implementation of project-based learning increases students' motivation to learn physics. This result is not consistent with findings from previous research, where it was established that project-based learning can enhance motivation for learning across various educational levels and contents (Harmer & Stokes, 2014; Shin, 2018), especially when incorporating information and communication technologies (Jusoff et al., 2010; Neo & Neo, 2005; Safaruddin, 2020). In addition, projects that use information and communication technologies can create authentic, meaningful, collaborative, and active learning environments (Henderson et al., 2010). The lack of positive effect of project-based learning on motivation might be due to students predominantly learning with the sole aim of passing exams and being accustomed to conventional exams. Although during the discussion the students of each group declared that all members of the group were equally engaged and that they shared tasks among themselves during the execution of the project, the researcher observed that some groups were less explicit about how each member was involved. It is possible that students provided socially desirable responses, and a number of students might not have been sufficiently engaged in the project work. This could have been caused by the fact that students were not individually assessed, but rather the evaluation pertained to the group, i.e., the project. Furthermore, the project-based learning content partially exceeded the mandatory subject matter, and the reward of only five exam points may have been perceived as not valuable enough by the students. In line with the mentioned, students probably did not see the benefit in the applied approach but merely recognized that additional effort was required of them. Additionally, students' previous experiences in physics classes and learning in general influenced their motivation levels, and making a change at their age may not be easy.

Implemented project-based learning positively influenced the metacognition of certain student groups, considering the whole sample as well as separately for male and female students and physics students. However, no statistically significant difference in metacognition before and after the introduction of project-based learning was observed in other student groups, particularly among technology students and students with different academic achievements. Throughout the project, students independently monitored their work to solve problems and draw conclusions within the project tasks. They conceptualized their ideas to prepare project presentations. Given that project-based learning encourages the processes of cooperation and evaluation (Thomas, 2000; Torp & Sage, 1998), it has been proven that its implementation with the use of cooperative structures in the form of small groups facilitates mutual communication among students, and positively affects the development of interpersonal relationships. Besides, this implies individual and group responsibility in fulfilling proposed tasks. Students identify certain limitations in evaluating their work and propose solutions for exerting more control over those in the group who do not contribute to the tasks, such as insisting that such individuals undertake the individual development of their project (de la Torre-Neches et al., 2020).

Project-based learning has been shown to facilitate the development of students' metacognitive abilities (Lukitasari et al., 2021; Payoungkiattikun et al., 2022). However, the lack of a positive effect of project-based learning on the metacognition of certain groups of students was observed (Table 2). This may be due to their insufficient engagement and failure to embrace this approach in the right way.

Additionally, the limitations of the research that could have minimize the expected positive effects of implementing project-based learning should be indicated. Firstly, although a scale frequently used in research was employed to assess metacognition, it measures only specific metacognitive components based on self-assessment. Moreover, motivation was measured using a self-assessment scale. It should be noted that students are not accustomed to project-based learning, and for exam purposes, they often choose to reproduce content as accurately as possible to avoid making mistakes. There is a possibility that students did not fully grasp the way of working within the project activities, meaning they did not efficiently coordinate their activities in the group. This could result in certain limitations in mutual communication and/or unequal efforts among individuals. According to student reports, all projects had a clear goal and a somewhat clear work plan, but not precise enough deadlines for task execution. Although groups were formed based on previous collaboration and good communication among members, it seems that during project work, a certain type of communication was lacking, which should enable members to be more informed about the process of executing tasks by other members, directly impacting mutual support in achieving a common goal.

CONCLUSION

Based on the analysis of research results, it can be concluded that the implementation of project-based learning in the processing of university physics content has successfully stimulated the development of students' metacognition. However, it did not significantly impact students' motivation to learn. The analysis indicated in which student groups the positive effects of implementing project-based learning on students' metacognition are significant.

Based on the research results, it can be concluded that within university education, there is a need to allocate specific time for the implementation of project-based learning, especially when dealing with content suitable for such an approach. This way, students, while mastering the prescribed content, would develop metacognition, further preparing them for lifelong learning. The interdisciplinary approach also contributes to students' competencies for future work. Since project-based learning has begun to be applied at lower education levels, a significantly greater positive impact on future generations of students accustomed to such an approach can be expected. Until then, a way needs to be found to make working on projects more accessible to students, preparing them for future life and work challenges. Students need to understand the importance of project work. Additionally, the lack of impact of project-based learning on students' motivation indicates the need to consider student engagement in project work when evaluating their performance.

Based on the results of this research, it can be suggested that future studies should examine whether with students «trained» and accustomed to project-based learning greater positive impacts would be shown, that is, would they derive more benefits from the implementation of project-based learning. The reasons why the positive impact on students' motivation was lacking, as well as the reasons for the absence of a positive impact on the metacognition of technology students, should be confirmed in future studies. Exploring whether students can be motivated in this way and whether the interdisciplinary approach contributes to students' deeper commitment to the studied content, resulting in higher achievements and acquiring more comprehensive and lasting knowledge, can be done. Moreover, in future research, motivation and metacognition can be measured in different ways (for example, applying metacognition during project-based learning), other components of these variables can be considered, and other student traits relevant to the teaching process can be explored to gain a more detailed understanding of the impact of project-based learning at the university level. To consider all advantages of project-based learning, it is important not to overlook investigating its positive impact on students' social skills, readiness for teamwork, communication abilities, and other competencies developed through the implementation of project-based learning in the form of group work.

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Received 19.3.2023; accepted for publishing 17.9.2023.

APPENDICES

Appendix 1
Questionnaire on Motivation to Learn

For each of the following statements, indicate how much it corresponds to your opinion by circling the appropriate number according to the scale provided below.

Numbers 1 to 5 have the following meaning:
1 = Strongly Disagree,
2 = Disagree,
3 = Undecided,
4 = Agree,
5 = Strongly Agree.

1.	Whether the content is difficult or easy, I am sure that I can understand it.	1 2 3 4 5
2.	I am not confident about understanding difficult concepts.	1 2 3 4 5
3.	I am sure that I can do well on written exams.	1 2 3 4 5
4.	No matter how much effort I put in, I cannot learn content.	1 2 3 4 5
5.	When problems are too difficult, I only do the easy parts.	1 2 3 4 5
6.	During learning activities, I prefer to ask other people for the answer rather than think for myself.	1 2 3 4 5
7.	When I find some content difficult, I do not try to learn it.	1 2 3 4 5
8.	When learning new concepts, I attempt to understand them.	1 2 3 4 5
9.	When learning new concepts, I connect them to my previous experiences.	1 2 3 4 5
10.	When I do not understand a concept, I find relevant resources (additional literature, internet) that will help me.	1 2 3 4 5
11.	When I do not understand teaching material concept, I would discuss with the teacher or other students to clarify my understanding.	1 2 3 4 5
12.	During the learning processes, I attempt to make connections between the concepts that I learn.	1 2 3 4 5
13.	When I make a mistake, I try to find out why.	1 2 3 4 5
14.	When I do not understand the teaching material, I still try to learn it.	1 2 3 4 5
15.	When new content that I have learned conflict with my previous understanding, I try to understand why.	1 2 3 4 5

16.	I think that learning physics is important because I can use it in my daily life.	1 2 3 4 5
17.	I think that learning physics is important because it stimulates my thinking.	1 2 3 4 5
18.	In physics, I think that it is important to learn to solve problems.	1 2 3 4 5
19.	In physics, I think it is important to participate in inquiry activities.	1 2 3 4 5
20.	It is important to have the opportunity to satisfy my own curiosity when learning physics.	1 2 3 4 5
21.	I learn to get a good grade.	1 2 3 4 5
22.	I learn to perform better than other students.	1 2 3 4 5
23.	I learn so that other students think that I'm smart.	1 2 3 4 5
24.	I learn so that the teacher pays attention to me.	1 2 3 4 5
25.	I feel fulfilled when I attain a good score in an exam.	1 2 3 4 5
26.	I feel fulfilled when I feel confident about my knowledge.	1 2 3 4 5
27.	I feel fulfilled when I am able to solve a difficult physics problem.	1 2 3 4 5
28.	I feel fulfilled when the physics teacher accepts my ideas.	1 2 3 4 5
29.	I feel fulfilled when other students accept my ideas.	1 2 3 4 5

Appendix 2
Questionnaire on Metacognition

For each of the following statements, indicate how much it corresponds to your opinion by circling the appropriate number according to the scale provided below.

Numbers 1 to 5 have the following meaning:
1 = Strongly Disagree,
2 = Disagree,
3 = Undecided,
4 = Agree,
5 = Strongly Agree.

1.	I ask myself periodically if I am meeting my goals.	1 2 3 4 5
2.	I consider several alternatives to a problem before I answer.	1 2 3 4 5
3.	I try to use strategies that have worked in the past.	1 2 3 4 5
4.	I pace myself while learning in order to have enough time.	1 2 3 4 5
5.	I think about what I really need to learn before I begin a task.	1 2 3 4 5
6.	I know how well I did once I finish a colloquium / test / written exam even before I check the answers with my friends or the professor reviews it	1 2 3 4 5
7.	I set specific goals before I begin a task.	1 2 3 4 5
8.	I consciously focus my attention on important information.	1 2 3 4 5
9.	I learn best when I know something about the topic.	1 2 3 4 5
10.	I know what the teacher expects me to learn.	1 2 3 4 5
11.	I use different learning strategies depending on the situation.	1 2 3 4 5
12.	I ask myself if there was an easier way to do things after I finish a task.	1 2 3 4 5
13.	I have control over how well I learn.	1 2 3 4 5
14.	I periodically review to help me understand important relationships.	1 2 3 4 5
15.	I think of several ways to solve a problem and choose the best one (the one that will solve the problem most easily and efficiently, correctly and accurately).	1 2 3 4 5
16.	I can motivate myself to learn when I need to.	1 2 3 4 5
17.	I am aware that when I study, I use certain learning strategies.	1 2 3 4 5
18.	I create my own examples to make information more meaningful.	1 2 3 4 5

19.	I am a good judge of how well I understand something.	1 2 3 4 5
20.	I find myself using helpful learning strategies automatically.	1 2 3 4 5
21.	I find myself pausing regularly to check my comprehension.	1 2 3 4 5
22.	I ask myself how well I accomplish my goals once I'm finished.	1 2 3 4 5
23.	I draw pictures or diagrams to help me understand while learning.	1 2 3 4 5
24.	I ask myself if I have considered all options after I solve a problem.	1 2 3 4 5
25.	I change my approach when I fail to understand something.	1 2 3 4 5
26.	I ask myself if what I'm reading is related to what I already know.	1 2 3 4 5
27.	I organize my time to best accomplish my goals.	1 2 3 4 5
28.	I learn more when I am interested in the topic.	1 2 3 4 5
29.	I try to break studying down into smaller steps.	1 2 3 4 5
30.	I ask myself questions about how well I am doing while I am learning something new.	1 2 3 4 5
31.	I stop and reread when I get confused.	1 2 3 4 5
32.	I stop and go back over new information that is not clear.	1 2 3 4 5

Appendix 3

Table: Results of Shapiro-Wilk Normality Test

	Student Group	W	df	p
Metacognition – Initial	Male	0.934	16	0.285
	Female	0.964	46	0.166
	Physics	0.965	20	0.654
	Technology	0.985	42	0.854
	High performance	0.936	21	0.184
	Average performance	0.969	26	0.597
	Low performance	0.966	15	0.798
Motivation – Initial	Male	0.909	16	0.114
	Female	0.963	46	0.152
	Physics	0.819	20	0.200
	Technology	0.977	42	0.538
	High performance	0.985	21	0.980
	Average performance	0.946	26	0.182
	Low performance	0.888	15	0.062
Metacognition – Final	Male	0.942	16	0.375
	Female	0.967	46	0.215
	Physics	0.982	20	0.954
	Technology	0.961	42	0.156
	High performance	0.979	21	0.918
	Average performance	0.985	26	0.953
	Low performance	0.881	15	0.050
Motivation – Final	Male	0.963	16	0.721
	Female	0.972	46	0.337
	Physics	0.963	20	0.613
	Technology	0.979	42	0.610
	High performance	0.949	21	0.332
	Average performance	0.969	26	0.590
	Low performance	0.939	15	0.368